AEROSPACE
Assuring Space Mission Success

Above & Beyond

Enabling Growth to 63 GPS Satellites

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GPS SIS ISs -- Open Forum

Pleasant News!

Pleasant, Pleasant, Pleasant…

- Have a pleasant problem
  - *Really more of an unexploited opportunity*
- Have a pleasant solution
  - *Growth path identified, planned, and underway*
- Result is pleasant news for all GPS users
  - *Now enable constellation expansion above and beyond 32 satellites*

Pleasant Problem

Unexploited Opportunity

- Currently have 38 satellites on orbit
  - *Mix of IIA, IIR, IIR-M, and IIF satellites*
- But… Can only have 31 satellites in today's constellation
  - *Only 32 almanacs in the legacy navigation (LNAV) message*
  - *Limited to 31 almanacs for operational reasons*
- Means therefore have 7 "residual" satellites
  - *Special meaning to the word "residual"*

GPS Satellite Status Terminology

From SPS PS

- Operational Satellite
  - *In the broadcast almanac*
- Primary Satellite
  - *Operational satellite filling slot in "Expandable-24" constellation*
- Auxiliary Satellite
  - *Operational satellite not filling slot in "Expandable-24" constellation*
- Residual Satellite
  - *Special meaning to the word "residual"*
    - Non-operational satellite, not in broadcast almanac, could be anywhere

GPS Constellation Requirements

Based on SPS PS

	IS-GPS-200	Accuracy	Integrity	Continuity	Availability
Primary Satellites	Must Meet	Must Meet	Must Meet	Must Meet	Must Meet
Auxiliary Satellites	Must Meet	Must Meet	Must Meet	N/A	N/A
Residual Satellites	N/A	N/A	N/A	N/A	N/A

Why Have Auxiliary Satellites?

- Primary satellites must meet all requirements in SPS PS
  - *24 slots → 24 primary satellites*
  - *Expandable-24 constellation → 24/25/26/27 primary satellites*

- Auxiliary satellites provide:
  - *Opportunity to improve GPS service using satellites outside of the defined primary slots*
  - *Opportunity to leverage on-orbit satellites that may have continuity or availability issues but otherwise meet ICD, accuracy, and integrity requirements*

Why Have Residual Satellites?

- Auxiliary satellites must meet minimum requirements at least
  - *Minimum auxiliary satellite requirements are: ICD, accuracy, integrity*
  - *Should also have good availability and continuity*
- Residual satellites provide:
  - *Opportunity to preserve useful on-orbit satellites exceeding almanac size limitations*
  - *Opportunity to preserve on-orbit satellites that may not meet every requirement*

Result for GPS Constellation Management

- Keep best 24 satellites as Primary Satellites in 24 slots
  - *Must meet all requirements in SPS PS*
- Next best satellites are the Auxiliary Satellites
  - *Must meet ICD, accuracy, integrity requirements in SPS PS*
- Residual Satellites are extras that still have potential use

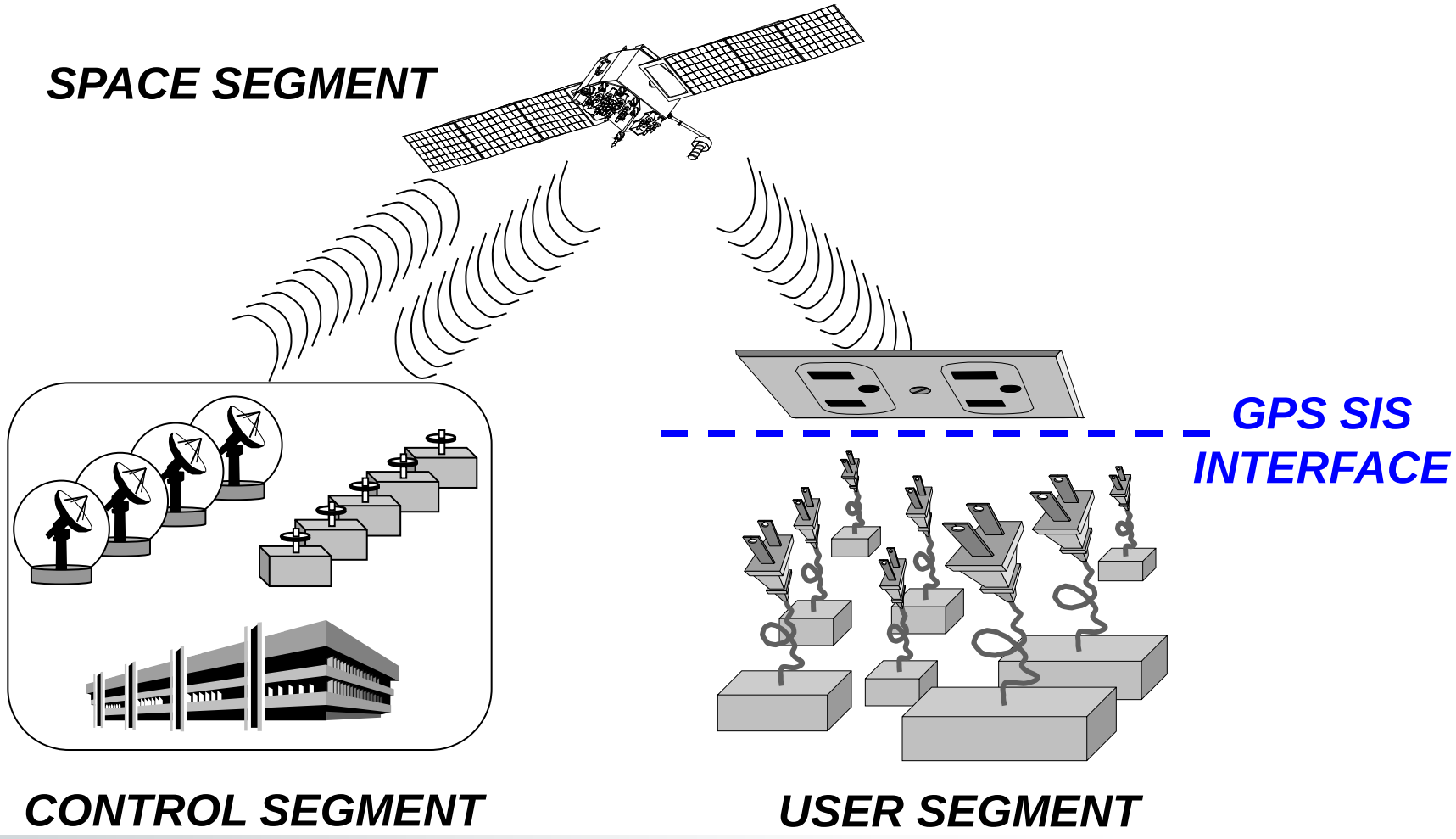
GPS Constellation Management

Derived from SPS PS

	IS-GPS-200	Accuracy	Integrity	Continuity	Availability
Primary Satellites	Must Meet	Must Meet	Must Meet	Must Meet	Must Meet
Auxiliary Satellites	Must Meet	Must Meet	Must Meet	Might Meet	N/A
Residual Satellites	May Meet	May Meet	May Meet	May Meet	N/A

Golden Opportunity for Modernization

Existing Resources



Pleasant Solution

Some Existing, Some Underway, Some Planned

- Signal-in-Space (SIS) Interface
  - *IS-GPS-200H is here!*
    - Also IS-GPS-705D & IS-GPS-800D!!
- Space Segment
  - *Unexploited Block II satellite capabilities*
  - *GPS III satellites are coming!*
- Control Segment
  - *Next Generation Operational Control System (OCX) is coming!*

IS-GPS-200 Historical Vector

How we got here

Year	ICD	PRN Codes	Almanacs
1975	MH08-00002-400	32(+5) C/A Codes	24
1983	ICD-GPS-200	32(+5) C/A Codes	32
2003	ICD-GPS-200C, R5	32(+5) C/A Codes 32(+5) L2C Codes	32 Up to 63
2004	IS-GPS-200D*	32(+5) C/A Codes 32(+5) L2C Codes	32 Up to 63
2006	IS-GPS-200D, R1	32(+5) (+173) C/A Codes 32(+5) (+52) L2C Codes	32 Up to 63
2010	IS-GPS-200E	32(+5) (+173) C/A Codes 32(+5) (+52) L2C Codes	32 Up to 63

* Incorporated New & Improved Clock & Ephemeris (NICE) data for CNAV

Legacy NAV (LNAV) Message Limitation

Clever Solution

- Legacy NAV (LNAV) message structure/content is inviolate
  - *Must maintain backward compatibility*
    - Failure =  (“skull & crossbones”, poison, fate worse than death)
- Parallel LNAV message structure/content is clever solution!
  - *Parallel but separate constellations (“parallel/separate universes”)*
  - *Lower PRN constellation (1-32) & Upper PRN constellation (33-63)*
  - *100% backward compatible*
- Approved at ICWG for IS-GPS-200F on 13-15 Sep 11
  - *“PRN Expansion” for LNAV messages and C/A codes*

PRN Expansion in IS-GPS-200F/G/H

Technical Details

- Parallel Universes: parallel LNAV message structure
  - *Current limit is 31 satellites in range of PRN-01 through PRN-32*
  - *Parallel limit is 31 satellites in range of PRN-33 through PRN-63*
  - *Parallel LNAV message structure/format allows for software re-use*
- Separate Universes: separate LNAV message content
  - *Lower PRN constellation makes no reference to upper PRN constellation*
  - *Upper PRN constellation makes no reference to lower PRN constellation*
  - *Separate LNAV message content ensures backward compatibility*
    - Unmodified, today's receivers won't even know higher PRNs exist
- Civil NAV (CNAV) message structure/content is different
  - *Designed to handle up to 63 PRNs from the very start*

Backward Compatible PRN Expansion

Parallel/Separate Universes

	L1 C/A Lower PRN Constellation PRN 1-32, LNAV	**L1 C/A** Upper PRN Constellation PRN 33-63, LNAV	**L2C** Full PRN Constellation PRN 1-63, CNAV
Current Receiver L1 C/A	Same As Ever	Oblivious	Oblivious
Updated Receiver L1 C/A	Half of Almanac Database	Half of Almanac Database	Oblivious
Current Receiver L1 C/A & L2C	Same As Ever	Oblivious	Ignore PRNs 33-63
Updated Receiver L1 C/A & L2C	Secondary Source of Almanac Data	Secondary Source of Almanac Data	Primary Source of Almanac Database

Implementing PRN Expansion

More Technical Details

- System limitations for PRNs 33-37
  - *PRN 33 not suitable for satellite use*
  - *PRN 37 now in use for SatZap procedure*
    - Should not use for operations until SatZap procedure retired
  - *PRNs 34 and 37 have identical C/A-codes*
    - Should not use for operations until antipodal satellite pair identified

Space Segment

Implementation Details

- IIA, IIR, IIR-M, and IIF satellites can operate as PRNs 1-37
  - *Built-in capability*
  - *Ready to go as PRNs 33, 34, 35, 36, 37*
    - IIA & IIR-M = L1 C/A
    - IIR-M = L1 C/A & L2C
    - IIF = L1 C/A & L2C & L5
- GPS III satellites will be able to operate as PRNs 1-63
  - *Building in the full expanded capability (on contract)*
    - III = L1 C/A & L2C & L5 & L1C

Control Segment

Implementation Details

- Today's OCS cannot handle PRNs 33-63
  - *Database limited to handling PRNs 1-32*
- Future OCX will handle satellites operating as PRNs 1-63
  - *Building in the full expanded capability (on contract)*
- Future OCX will also handle NANUs & etc. for PRNs 1-63
  - *Also building in the full expanded capability (on contract)*
    - ICD-GPS-870 replacing ICD-GPS-240

Hypothetical Transition Plan

Gazing into the Crystal Ball – Caveat Emptor

- Pacing element is OCX
- Once OCX comes on-line towards end of the decade
  - *Predict seeing a IIR-M satellite enter service as PRN-35*
    - L1 C/A and L2C
- Once last IIA satellite dies and SatZap no longer needed
  - *Predict seeing another IIR/IIR-M satellite enter service as PRN-34*
- Eventually see quite a few IIIs as PRNs 34-63

Summary

Pleasant Problem, Pleasant Solution

- Have 7 residual satellites today that cannot be used
  - *Unexploited opportunity, unexploited resources already on-orbit*
- Have program to allow residual satellites to re-enter service
  - *Timeline is towards the end of the decade*
  - *100% backward compatible, no user downside*
- Able to go above & beyond today's limit of 31 satellites
  - *Whether bringing residuals back on-line or expanding constellation*

If you build it, they will come...

Questions?

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